

Summary Report for Out-of-Pile Transient Testing Database Development

Nuclear Engineering Division

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prepared by Carolyn A. Tomchik
Nuclear Engineering Division, Argonne National Laboratory

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Summary

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The DOE Advanced Reactor Technology program has supported knowledge preservation efforts to recover and preserve fuel data from the US sodium cooled fast reactor (SFR) program. Efforts have focused on establishing databases of experimental data generated during the Integral Fast Reactor program (at EBR-II, FFTF, and TREAT) as well as during related out-of-pile examinations of the fuel irradiated at EBR-II. The information in these databases is essential to support further development and licensing activities for advanced fast reactor designs. OPTD is a database of out-of-pile furnace transient tests on metallic fuel. It includes records of 62 tests on irradiated fuel pins conducted in furnace apparatuses constructed in the Alpha-Gamma Hot Cell Facility at ANL. This report describes efforts during FY19 to improve visibility and access, expand the content of, and improve the user experience with the FIPD and OPTD databases.

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1 VISIBILITY AND ACCESS TO FAST REACTOR DATABASES

The DOE Nuclear Energy Advanced Reactor Technology (ART) Program has supported the creation of several databases with information describing the safety performance of fast reactors, components, and fuels. This growing collection of legacy experimental data, operating data, and analysis is available on the web to registered users through individual databases. While this data is extremely valuable, the number of users utilizing the collected resources has remained relatively small. Efforts this year have therefore focused on improving visibility of and access to these databases, with the aim of making as much data available to as many nuclear industry and research users as possible. Progress has been made during FY2019 in informing people not only about the existence of these databases, but about the kind of content they can find in each.

1.1 Fast Reactor Databases (FRDB) Central Page

A central landing page, located at <https://frdb.ne.anl.gov/>, was developed in order to provide a singular website to advertise via DoE, GAIN, and other channels to bring potential users information about all of the ART databases. It is likely that a user who has heard of and is interested in one database may find value in the related databases; this central page can therefore help increase awareness of the full collection of resources. Databases developed by the Argonne Nuclear Science and Engineering (NSE) Division are described on the FRDB page. The page includes for each database: a link to its landing page, a brief description of the database contents, and instructions for who can get access and how to request it. The Argonne-developed databases are accessible using Argonne account credentials, after access requests are approved. Argonne collaboration accounts are provided to external users to facilitate access. Databases created by Sandia and Pacific Northwest National Laboratories are also linked from the FRDB page, with access and maintenance handled by their representative institutions.

1.2 Public Landing Pages and Access Controls for Each Database

Each of the Argonne databases now includes a public landing page and some publicly-accessible content. In other words, a user is able to access limited parts of the site before obtaining a user account or signing in. Information available on the public pages for each database includes: description of the experimental program and/or facilities, description of the content and structure of the database, and instructions for requesting an account to access database records. OPTD has limited access to Argonne users until such time as more of the records in the database can be made available to external users. It is intended for the sites to ultimately utilize the tiered access system used for the TREXR database, described in ANL-ART-127 [1].

2 OPTD: OUT-OF-PILE TRANSIENT DATABASE

2.1 Introduction and Testing Program

The Integral Fast Reactor (IFR) program, active from 1984 to 1994, produced a large collection of data relating to the performance of metallic fuels in sodium-cooled fast reactors (SFRs). To evaluate fuel/cladding compatibility, tests were conducted under both steady-state and transient conditions. Steady-state tests were first conducted within test reactors to evaluate fuel performance during normal reactor operating conditions. During steady-state reactor operation, solid state interdiffusion at the fuel-cladding interface within a fuel pin causes slight cladding wastage, which is highly dependent on the local power, temperature, and burnup of the fuel. While this wastage is not a concern under normal operating conditions, the metallic fuel pin may be more vulnerable to off-normal events (e.g., loss of coolant flow, loss of a heat sink, or transient overpower events). Transient tests are then needed to evaluate fuel performance during these off-normal events. During these transient scenarios, the fuel pin will experience elevated temperatures, at which uranium and plutonium from the fuel can react with iron and other components in the cladding, forming liquid phases (eutectic formation). The eutectic formation at the fuel-clad interface reduces the cladding thickness and may compromise its integrity. While these off-normal events can be simulated in-pile (e.g., in the TREAT reactor), they can also be simulated out-of-pile by raising fuel samples rapidly to high temperatures representative of these accident scenarios. The transient testing conducted in the Alpha-Gamma Hot Cell Facility (AGHCF) used irradiated fuel samples from EBR-II with fuel-clad interfaces prototypic of those found in an operating reactor. Records from the transient tests conducted out-of-pile in the AGHCF are being archived in the Out-of-Pile Transient Database (OPTD).

2.1.1 IFR Fuel Compatibility Testing

For a clearer picture of where the AGHCF furnace transient tests fit in the larger landscape of IFR fuel compatibility testing, they can be compared to both the transient testing conducted in TREAT and the steady-state testing conducted in EBR-II. The tests of metallic fuels conducted in EBR-II were lower temperature, steady-state tests to demonstrate the performance of the fuel under normal operating conditions. Records of these EBR-II tests can be found in FIPD [2] and PADB [3]. An extensive long-duration transient testing program was also conducted at EBR-II as documented in the EBR-II Transient Test Database (ETTD) [4]. The transient tests conducted on metallic fuels in the TREAT reactor were high temperature, short duration transient tests to demonstrate the fuel behavior under rapid transient conditions, and their records are found in the TREXR database [5]. The AGHCF furnace tests included in OPTD bridge the gap between the EBR-II and TREAT testing conditions; they exposed irradiated fuel samples to elevated, accident-scenario temperatures for times in the range of minutes to hours, as shown in Figure 1.

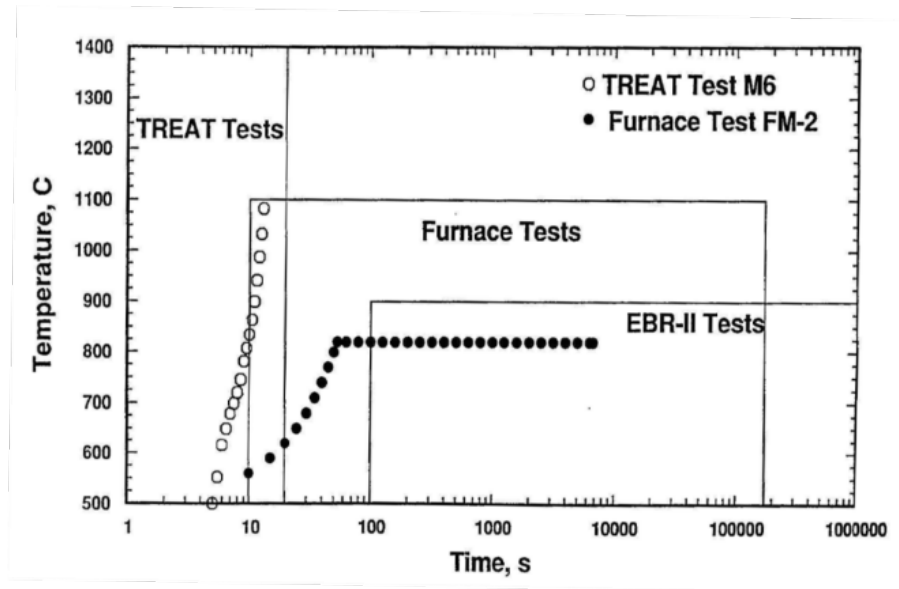


Figure 1: Testing regimes for in-reactor and out-of-pile tests on metallic fuels [6].

2.1.2 Furnace Transient Tests and Results

The out-of-pile furnace transient tests included in OPTD were conducted in two different furnace apparatuses: the Whole Pin Furnace (WPF) and the Fuel Behavior Test Apparatus (FBTA). Before the testing routine began, pre-test examinations of the fuel and cladding were made to characterize the as-irradiated structure. To begin the temperature transient test, the sample was installed in the furnace and slowly ramped to a pre-test, priming temperature. When the prescribed furnace transient routine was run, the temperature was increased at a predetermined rate (ramp rate) to a peak target temperature. A representative furnace testing routine is shown in Figure 2. The sample was held at the target temperature for a designated period of time or until pin failure. The furnace was scrammed when the test end condition was met (either at the end of the test time, or when pin failure was detected by a pressure spike), and the pin was then allowed to cool by convective heat loss. Following each test, data was collected and post-test examinations were made of the sample.

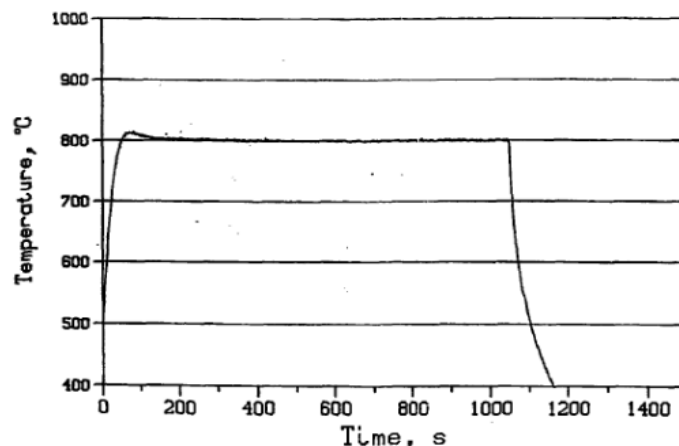


Figure 2: Furnace testing routine [7].

The FBTA tests were conducted on more than 50 fuel pin segments extracted from EBR-II fuel pins at constant temperatures from 700 to 850°C for durations from a few minutes up to 7 hours (most had a 1 hr duration). Fuels tested were U-10Zr and ternary fuels (up to U-26Pu-10Zr), with claddings composed of HT9, D9, or 316 stainless steel and peak burnups from 3 to 17%. The results of the FBTA tests established the time- and temperature-dependence of eutectic cladding penetration. The Whole Pin Furnace (WPF) tests were conducted on *intact* fuel pins from EBR-II, rather than segments, to study synergistic effects of fission gas pressure loading and fuel-cladding interaction. Seven WPF tests determined modes of pin failure, established safety margins and fuel failure thresholds, and examined fuel motion within the pin. More detailed descriptions of the furnace apparatuses, tests conducted, and key results can be found in [8].

The findings of the out-of-pile tests contributed to the safety case for metallic fuels in fast reactor applications. For most transient events, liquid phase formed only in the region of the sample where there was preexisting cladding wastage (from the steady-state irradiation). Only if the transient was particularly prolonged could the eutectic reaction progress further, into previously unaffected areas of the cladding. For brief, “design basis” transients (of durations seconds to minutes), there was no evidence of eutectic formation below 775 °C in even the “worst case” EBR-II pins (with the highest power, cladding temperatures, and burnups). For longer transients beyond design basis events, eutectic formation was seen in the worst-case pins at ~675 °C. For pins that were subject to less aggressive irradiation conditions, the eutectic formation temperature was another 50 °C higher. While the irradiation conditions pins experienced in EBR-II affected the eutectic threshold temperature, it was found they did *not* affect the rate of transient-induced cladding wastage. It is worth noting that the “worst case” pins in EBR-II presented a particularly challenging set of conditions, as the highest power, cladding temp, and burnup are experienced at the same location, near the fuel top, because of the flat axial power profile. These fuel survivability results are highly relevant for designers intending to use metallic fuels for modern reactor designs.

2.2 OPTD Content and Structure

The term “database” is used here to refer to an ordered and indexed library of information. The OPTD exists as a digital archive of scanned and saved records of documents (in pdf form) and accompanying spreadsheets of tables storing the related metadata. The database can be thought of as having three main components: A table of metadata describing the out-of-pile furnace tests, a digital archive of records relating to those tests, and a table describing each of the records.

The database is constructed to contain details and descriptions of each test conducted in the FBTA and WPF test apparatuses. These details include test objectives, experimental parametric information, and sample descriptions. For each of the tests, there exists a collection of related records ranging from informal, internal memoranda to formal programmatic progress reports, conference submissions, and other publications. Each record must be tagged according to its category and content. This metadata is then linked such that tests and records with similar characteristics can be related (e.g., tests conducted on the same fuel/clad combination or

documents containing test design specifications). The database is made available to and end user through a web interface.

2.3 Status and Progress

The hard copy records pertaining to the out-of-pile furnace tests were collected, scanned, and saved as text-searchable pdf files in a digital archive during FY2018. Only a handful of additional records were found and added during FY2019. Effort during FY2019 has been dedicated primarily to reviewing these scanned files and extracting relevant metadata to appropriately fill in the tests and records metadata tables, altering the structure of the tables as needed to accommodate details of tests and records. This is a time-consuming and often iterative process, and therefore estimates of completeness are approximate.

2.3.1 Progress for FY2019

Because of particular interest in the Whole Pin Furnace tests, work has focused on reviewing records of and completing entries related to all WPF tests first. In response to urgent interest from researchers working on BISON code validation, abbreviated benchmarking descriptions of the testing routine and measurements made during the FM-4 and FM-6 WPF tests on U-19Pu-10Zr/HT9 pins (DP-22 and DP-39 from EBR-II subassembly X441A) were compiled and provided directly to code developers. The WPF test table entries describing the details of each test are approximately 85% complete and currently include test name, date, brief description, lead experimenters, experimental objectives, test pin details, and test temperature and duration. Completion of the entries describing the transient measurements taken during the test, post-test-analyses conducted, and post-test examination measurements available in the records is in progress. Records entries describing the characteristics of each WPF-related file are ~50% complete. Entries currently include the bibliographic information (e.g., filename, title, authors, date, and access categories), but review to identify all tests each record relates to as well as the particular content in each record (e.g., experiment design plans, diagnostic descriptions, PIE results, etc.) is in progress.

The FBTA-related entries are estimated to be less than 20% complete, as records describing these tests are sparser and more difficult to identify (tests were not often referred to by name within documentation). While the FBTA tests were initially thought to number ~50-70, references have now been found to over 100 individual tests. The fraction of these tests that have sufficient recorded detail to be relevant remains to be seen. Review of all found records related to the out-of-pile tests must be completed before a determination can be made.

The web interface for OPTD has been built, but awaits more complete metadata tables so that it can be populated with relevant information.

2.3.2 Future Work and Plans for FY2020

Review of scanned records to complete all metadata tables is expected to continue throughout FY2020. Once a sufficient number of records have been reviewed and tagged, the web interface will be populated and user accounts to access the available information can be granted to interested

persons. It should be noted, however, that most of the records are internal and will not be viewable by non-DoE users until they are formally reviewed for release.

While the pin identification for each sample is indicated in the database, it is not presently linked to the full subassembly and irradiation history information provided in existing EBR-II databases. It may be advantageous to link directly to subassembly and irradiation history information in the future, but this would require coordination between other databases to avoid redundantly reproducing the subassembly information locally.

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Argonne National Laboratory
9700 South Cass Avenue
Lemont, IL 60439

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